An Overview of Crater Analyses, Tests and Various Methods of Crater Detection Algorithm

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Abstract

This paper focuses on review articles of crater detections, analyses, tests and pattern recognition methods. Various methods of detection and analyses are compared according to their implementations, procedures and results. Nowadays, there are vast methods of crater detection algorithms and the most accepted one are by using Hough Transform analysis and edge detection algorithm. Nevertheless, some of them are implementing the detection based on illumination view that is the distinguishable between sunny and shady blob that formed a crater. Some of the methods are new and promising using stochastic image modeling. For crater detection algorithm, the edge based and edge free methods are compared according to their performances. The advantages and drawbacks of these techniques are summarized here.

Keywords

Crater Detection Algorithm; Crater Analyses; Image Processing; Ellipse and Circle Detection; Crater-Scaling Relationship; Hough Transform

Introduction

Crater phenomenaare very common in nature and the researches about crater are highly desired in spacecraft navigation. There are vast research and paperwork focused mainly in space crater analysis. There are numerous which is focused only for earth crater. Ever since the first craters were photographed from the satellite or spacecraft, there are various techniques have been used to determine the fundamental properties such as diameter and depth which can reveal the properties of the crater itself such as surface history and age or impact population.

Identification of these topographic features on planetary and earth surface by human experts can take such a long time consuming. Therefore, the researchers introduce reliable automatic recognition using detection algorithm. Different approaches have been presented based on pattern recognition technique, pattern matching, illumination condition (sunny and shady part of crater) and so on. A popular edge-based recognition technique has been implemented widely in spacecraft navigation and there are actually some necessary limits of this visual crater detection scheme.

Crater Detection Algorithm and Crater Analyses

Over the last 15 years, automated algorithms have been proposed to locate craters and determine the diameter and many of these are based on visual image rather than topography. The benefit of using topography to determine crater location is that the depth can be directly calculated as well [S.J Robbins et al, 2007]. In counter battery missile, the crater analysis objective is to determine the crater radius as well as the depth to locate the enemy's position through the estimation of the angle of flight from the mortar. The mortar's crater detection algorithm to estimate depth and angle of flight as well as its projectile motion algorithm to estimate the enemy's location are the main analyses in this paper.

Based on the depth estimation of space crater (Mars), a new automated method has been proposed by S.J Robbins et al. to treasure wealth information of the crater history and formation. The technique that used the Barlow database [Barlow et al., 2003] using Viking images of Mars is focuses on finding the rim of a 2-D azimuthally and radially binned crater profile. There is assumption made to reduce the 3-D topographic

profile by first assuming that all the craters are azimuthally symmetric. The algorithm then looks at the second derivative of the crater's profile to determine the most negative curvature near the crater's topographic highs assigning that location as the crater's rim [S.J Robbins et al., 2007].

Crater often uses as an ideal navigational landmarks either in space or earth. Nevertheless, the distribution of earth craters is significantly different to the distribution on other planetary bodies. This is because earth is more geologically active compare to the planetary surface. Besides, remnants of impact events are eroded or covered in sediment and the areas where we might expect to find impact structures aren't full of impact crater researchers [J. Earl et al., 2005]. Over past few years, they used the edge information based algorithm to detect craters. For space crater detection, Optical Landmark Navigation using craters was first used operationally by the Near Earth Asteroid Rendezvous (NEAR) mission [Jiang He et al., 2010]. This paperwork from Dalian, China used edge information based algorithm for detecting craters and matching. Crater matching based navigation method in landing course is implemented by measuring crater data on the lunar surface and comparing with crater database stored before the landing mission [Jiang He et al., 2010]. Using the edge based information; the author implemented the multi-scale adaptive Gaussian filtering and adaptive Canny algorithm using histogram of image to detect the craters. Then, the craters are extracted by several steps such as adaptive edge detection, edge selection, edge pairing and ellipse fitting.

Back in 2004, there's a research on observations and simulations of various velocities impact crater transition for a range of penetrator densities into thick aluminum target. Impact craters in a series of projectile/target system have been examined and compared to explore the effects of impact velocity and projectile density on crater formation. A 2-D impact crater computer simulation is performed using matching crater shapes and corresponding micro-hardness maps and compared to the measured crater geometry parameters in the experiment.

There are various methods in detecting craters using optical image. The JPL Machine Vision developed a powerful algorithm by using lighting source direction and edge convex properties, which achieved sub-pixel accuracy but lacked in adaptive ability to differentiate the imaging conditions [Cheng Y. et. al, 2005]. Flores Mendez etc. recommended algorithms based on Template Matching [Ansar A. et al., 2003]. Some are proposed an algorithm based on KTL (Kanade-Lucas-Tomasi) feature extraction. Sawabe et al. suggested a combinational algorithm using multi-methods to enhance the adaptive ability to differentiate crater size. In morphological image context, crater detection method can be comprises into two categories, detection based on area information and detection based on edge information. Basically, area information based techniques are influenced by illumination condition (sun elevation angle) while edge information has good stability since it is just depended on the shape of the crater rims and influenced by illumination rarely. The resulted crater detection by using adaptive crater detection algorithm is shown as Figure 1 below:

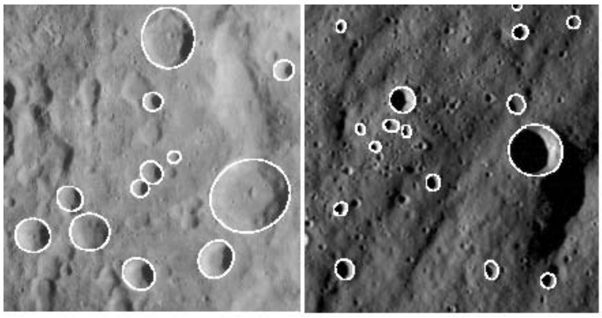

FIG. 1 CRATERS DETECTED USING EDGE AND ADAPTIVE CRATER DETECTION [Jiang He et al., 2010]

In 2009, there was a research on Large-diameter longhole blasting parameters of underground mine based on earth crater in Xinshan mining Area somewhere in China. This paper combines with Kafang's engineering practice of Xinshan mining area, makes crater tests, and then determines the blasting parameters (crater depth, radius, volume) under experimental conditions. The crater test is being held to determine the blasting parameters as well as the crater parameters under the experimental conditions. It works in medium-length hole blasting using Livingston Theory Blasting Crater Test which determines the crater similarity principle based on the best depth from the single hole's blasting crater test [Pan Dong et al., 2009]. The neural network should be use for prior optimal calculation of the blasting parameters on the basis of the tests is due to the uncertainties of rock properties and measurement errors in blasting tests and other factors that can lead the deviations of experimental data. The volume and radius versus charge depth curves are plotted and analyzed based on polynomial regression of blasting crater. The comparison analysis from the Livingston

crater test and neural network prediction showed a similarity in terms of charge depth, charge volume as well as the explosive consumption values [Pan Dong et al., 2009].

A geological earlier study showed that Malaysia has new revealed meteorite impact crater which located at Bukit Bunuh, Perak [M.N. KhairulArifin et al., 2010]. A latest 2009 preliminary study on magnetic gradiometer survey at Bukit Bunuh Perak was held by the researcher from USM to analyze the subsurface structure correspond to the crater. According to the examination, archeological research shows the evidence of shock metamorphisms (suevite breccia) and crater morphology (Bukit Bunuh Ring). The qualitative and quantitative measurement has been carried out to determine the depth estimation based on the anomalies patterns and forward data modeling using Talwani algorithm. Half width method is applied to resolve the depth estimation of the anomalies body (crater anomalies).

There was a parametric study on blast resistant analysis for a tunnel passing beneath Taipei Shongsan airport somewhere around 2006 by the National Taipei University candidates. The overall analysis evaluated are : the parameters of blast loading intensity, size of crater, dynamic undrained shear strength, dynamic Young's Modulus, and soil damping ratio to obtain the maximum lining thrust caused by a bomb explosion. Crater analysis has been carried out to estimate the bomb penetration depth and size. The final dimension of the crater is depend on type and amount of explosive, bomb penetration depth and the type of material in which the crater forms. If the explosion occurs deep enough to be completely contained below the surface, the true crater will consists of a cavity called a camouflet[US dept. of Army, 1986]. According the article by the US Army 1986, it is difficult to accurately calculate the bomb penetration depth, but estimation may be made by using the semi-empirical formula:

$$D_b = 3.2W_T^{0.333}$$

whereD_b is the bomb penetration depth in feet and W_T is the projectile weight in pounds. The factor 3.2 is depends on type of soil and also the corresponding energy loss during penetration in soil. In order to estimate the depth of mortar's bomb penetration, the author has adopted the same empirical formula as a first step before one can estimate the angle of firing mortar to estimate the enemy location. The impact angle with respect to the mortar's bomb may range from as low as 45 degrees until 80 degrees.

Various researches and studies have assessed the effect of critical independent variables on crater size, particularly in particulate targets [P.H. Schultz et al., 2005]. There were many experiments done to prove the crater-scaling relations over a wide range of projectile sizes and velocities. This paper discussed the empirical scaling relations widely used to estimate the crater dimensions. Laboratory impact experiment has been conducted at the NASA Ames Research Center to assess the range of possible outcomes for a wide range of target materials and impact angles. Impacts into competent targets results in craters with diameter limited by material strength; hence this is termed the strength-controlled-crater-scaling regime [Schmidt et al., 1977].While impacts into loose particulate targets however grow freely until gravity prevents material from escaping the cavity. This term called gravity-controlled-crater-scaling regime [Schmidt et al., 1977]. This paper mainly focused into size of the crater and what observations could be used to interpret the observed crater size and plume evolution.

To detect the craters in real world imagery, various techniques have been chosen and one of them is by using clustering-based circle detection. In year 2000, Mauro Barni et al. proposed the algorithm with respect to classical algorithms based on fuzzy shell-clustering. This algorithm is intended to make circle extraction robust against noise and non-circular structures. The proposed algorithm operated by grouping edge pixels into connected subgroups and by fitting a circle to each group through possibilistic clustering [Mauro Barni et al., 2000]. This algorithm was implementing several measurements including cluster initialization, circle extraction through possibilistic clustering, and cluster validation. Among circle detection techniques, those based on fuzzy clustering have widely used as an alternative to classical algorithms based on Hough Transform [Dave R.N., 1990] [Krishnapuram R. et al., 1992]. Fuzzy clustering has been used for ages to detect number of clusters with spherical symmetry [Bezdek, J.C., 1981]. However, by picking a suitable metric to measure the distances between data point and prototype and by swapping the cluster prototype from a point to a shell-like prototype, these two techniques can be applied directly to an edge imagery to fit image boundaries to straight lines, circles, ellipses and conics [Bezdek, J.C., 1981]. Moreover, this algorithm is defined by the form

of the prototypes and in this case the circular clusters prototypes were used.

An experimental research program was conducted to determine the cratering characteristics resulting from the impact of high velocity projectiles in 11 different metal alloys by the Lewis Research Centre, National Aeronautics and Space Administration (NASA) in early 1969. The relationship between projectile density and target temperature has been observed and the cratering formation and characteristics of these different tested materials were identified. In this paper, they studied the correlation of the projectile density effect as well as the ratio of the depth of penetration and diameter. The estimation of the crater depth in a thick target due to high velocity impact has been made with various empirical equations based on some physical strength property of the material [Nestor Clough et al., 1969]. An equation for estimated depth of penetration in various ranges of impact materials has been proposed with regards of modulus of elasticity and cratering coefficient at room temperature to be known. The equation for crater depth based on the target modulus elasticity is derived as [Summers et al., 1958]:

$$\frac{P_\infty}{d} = \gamma\left(\frac{\rho_p}{\rho_t}\right)^{2/3}\left(\frac{V}{\sqrt{\frac{E_t}{\rho_t}}}\right)^{2/3}$$

$$P_\infty = semi\ infinite\ penetration\ depth$$
$$d = projectile\ diameter, mm$$

$$\gamma = material\ cratering\ coefficent$$

$$\rho_p = projectile\ density, g/cm^3$$

$$\rho_t = target\ density, \frac{g}{cm^3}$$

$$V = projectile\ velocity, km/sec$$

$$E_t = modulus\ of\ elasticity, dyne/cm^2$$

According to the Paleontology Department, University of Bristol, the correlation between the kinetic energy of a meteor and diameter impacting the earth is derived as [Vanissra, B., et al., 2007]:

$$D = 0.07\ C_f\left(E.\frac{\rho_a}{\rho_t}\right)^{\frac{1}{3.4}}$$

D is the crater diameter while C_f is the crater collapse factor, ρ_a is the density of the projectile, ρ_t is the density of the target rock and E is the total energy of the meteor. Physics Institute of International School of Bangkok proved the equation through their experiment using a modified tennis ball, dropped into the sand from a fixed height, and the diameter of the crater formed were investigated. Since the ball is being dropped from the constant height, it is assumed that the ball is impacting with constant velocity [Vanissra, B., et al., 2007]. The diameter of crater is measured for various ranges of projectile masses and the average diameter is recorded. The crater diameter versus projectile energy graph was plotted and the relationship between them was proved using the equation of the form $D = k(E)^n$ where k and n are unknown constant.

Pattern and Shape Recognition on Detection Algorithm

Ellipse and circle detection is one of the key areas in analyzing the pattern and shape recognition of a crater. Moreover, the algorithm to detect lines and shapes are widely implemented in crater detection method using Hough Transform. In a real world image without pre processing, the algorithm is quite difficult to implement due to incomplete ellipse due to partial occlusion, noise or missing edges or outliers. Robust ellipse detection by fitting randomly selected edge patches algorithm was created by the researcher from King Mongkut's University of Technology Thailand using the RANSAC algorithm. It is an iterative method that finds and removes the best ellipse until no reasonable ellipse is found [Watcharin et al., 2008]. The best ellipse is chosen from randomly selected edge patches and the fitness is compared to the set threshold and the result is shown in figure 2 below:

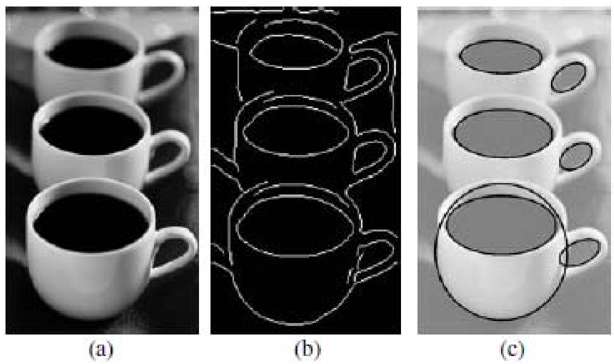

FIG. 2 (A) THREE CUP IMAGE (B) EDGE MAP (C) ELLIPSE DETECTED [Watcharin et al., 2008]

Another ellipse detection method is proposed by Han Fei et al. from Northeast Forestry University based on Hough Transform. This new method is proposed to improve the drawbacks from the standard Hough Transform method which require large computation and the large storage memory. Over the last two decade, many approaches have been developed,

among them; Hough Transform is the most famous algorithm [Hough, P.V., 1962] [Illingworth, J. et al., 1988]. Edge image after preprocessing is divided into several sub images to calculate the parameter of ellipses. Then the author used data merging method to process the parameter on both synthetic and real images. The experimental result shows that the proposed detector is capable to detect ellipse on real image with superior accuracy under various image conditions [Han Fei et al., 2009].

For hazard detection in space, detection schemes that based on edge detection and grouping in the way Cheng et al. proposed are most accepted by the researcher [Cheng Y. et. al, 2005]. Arguably, this is because of the simplicity, but also because of its relatively low complexity in computational demand that makes them suitable to the limited resources of spacecraft systems. This edge based algorithm is arguable may in fact be very useful in methods other than operating on visual imagery.

There are several limitations of this visual crater detection or simply known as edge-based detection method. As expression of the simplistic model of what a crater is expected to be (i.e circular, ellipses), the edge based steps are strictly heuristic because impact crater does change in size, age and stage of erosion [Pike R., 1977][Oberbeck, 1975]. This approach brought some constraints to raise on such as [BolkoMaass et al., 2011]:

- The modeling crater is too simple hence only a very small group of crater is successfully detected.
- The modeling crater is too elaborate that is the detection algorithm required too demanding space-qualified hardware and/or timing consumption needed.

The first constraint involved the edge based detection itself and the second involved in crater mapping procedures. Over the years, the methods of employing the global matching template is widely implemented to support automatic mapping recognition for craters detection but most of these operate in mapping scenarios and can assume favorable condition such as nadir facing camera or consistent illumination and relaxed requirements concerning computation time [BolkoMaass et al., 2011]. For automated navigation purposes, such drawbacks are unacceptable where pose-invariance is obliged for lost-in-space functionality or during spacecraft attitude changes when maneouvering [BolkoMaass et al., 2011].

Autonomous craters detection for planetary image has widely used in navigation upon landing purposes and is developed using several steps as mentioned previously and the accuracy rates are different. Some have employed texture analysis for crater detection [Toshihiko Misu et al., 1999][Barata et al., 2004]. They measure the variance in each tile and use shadows (high local variance) to detect crater or rocks but still they are using other algorithms for recognition of craters. However, the results presented were not very satisfied as it is not very accurate and the false alarm rate is also high. The JPL Machine Vision Group has developed the algorithm based on six stages: edge detection, crater anchor point detection, rim edge grouping, ellipse fitting, ellipse refinement and crater confidence evaluation [Ding Meng et al., 2008]. Among the some other different approaches worthy of mentioned, some have used template matching [M.C.Burl et al., 2001] [Michael et al., 2003] where pixel of the image arrays are rotated, translated or transformed to match piece of an image. This paper demonstrates an algorithm for crater detection based on feature points and ellipse detection. Besides, multi resolution window based KTL feature point extracting is implemented to analyze the candidate area of crater decision. Some image processing techniques are applied to spot craters and calculate its parameters as it being assumed as an ellipse.

Other new technique that employed pattern recognition in its final stage algorithm is crater detection based on Marked Point Processes (MPP). Although many automatic feature extraction procedures have been introduced for remote sensing images of the earth, these methods are typically unfeasible for planetary data that generally present low contrast and uneven illumination facial appearance. The main idea behind this practice is to model objects within a stochastic framework [Giulia Troglio et al., 2010]where a powerful methodology based on rigorous framework is introduced to efficiently map and detect features and structures in an image and it is robust to noise. In this case the extracted features are craters and the process is quite complicated since the planetary images are blurry, lack of contrast and uneven illumination plus the features are not good enough represented. Therefore, they introduced a detection based on marked point processes dealing with elliptical/bowl shape detection. MPPs worked from a set of complex geometrical objects in a scene which has been modeled and exploited for different functions in image processing

[Descombes X. et al., 2004]. The background is stochastic and the mission is to reduce energy on the state space of all possible configurations of objects, implementing a Markov Chain Monte Carlo (MCMC) algorithm and a Simulated Annealing (SA) scheme [Giulia Troglio et al., 2010].

Crater-Scaling Relationship

According to P.H Schultz et al., the final diameter and depth for simple (un-collapsed) craters are commonly assumed to form a constant ratio meaning that the crater diameter and depth are proportional. If the crater diameter is referenced to the pre-impact surface, it is termed the apparent crater and the aspect ratio ranges from 3:1 for the strength-controlled crater-scaling regime to 4:1 for gravity-controlled crater-scaling regime. Nevertheless, crater-scaling relationships indicated gravity controlled growth over a wide range of projectile type and sizes and velocities [P.H. Schultz et al., 2005].

The deep impact crater experiment study has been revealed some scaling relations that might be useful for the estimation of the crater's diameter and depth. For gravity-controlled, such scaling relations take the form of power laws relating dimensionless combinations of quantities describing the projectile and final crater [J.E Richardson et al., 2005]:

$$\pi_D = C_D \pi_2^{-\beta}$$

where π_D is a dimensionless measure of the crater diameter. The inverse of the Froude number π_2 can take this form in order to obtain the diameter of the crater:

$$\pi_2 = \frac{1.61gL}{v_i^2}$$

C_D and β are constants that are determine empirically and they are depends on the porosity of the target material. Table 1 below listed the values of these coefficients determine by [Schmidt and Housen, 1987].

TABLE 1 EXPERIMENTAL COEFFICIENT FOR DIAMETER ESTIMATION USING POWER LAW [Schmidt and Housen, 1987]

Target Material	C_D	β
Water	1.88	0.22
Loose sand	1.54	0.165
Competent rock or saturated soil	1.6	0.22

Conclusions

A review on craters detection algorithms, tests and analyses with various techniques and implementations are discussed. Although there are some limitations stated from the edge based technique, but still this arguably technique is the most popular between researchers. Hough algorithm with pattern and shape recognition is discussed which stressed on the ellipse detection process. However, there is also a new and hopeful technique using marked point process. The identification of craters is achieved by using a method based on MPP, coupled with a Markov chain and a simulated annealing scheme. Their performance and inherent shortcomings as well as their key weaknesses are identified for edge-based and edge free methods.

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